Dynamic Modeling of Marine Bioluminescence and Night Time Leaving Radiance

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LONG-TERM GOALS

The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments.

OBJECTIVES

Our objectives [in collaboration with Igor Schulman (NRL-Stennis) and Matthew Oliver (U Delaware)] are to develop the methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days, and to understand the coupled bio-optical and physical processes in the coastal zone that governs the variability and predictability of bioluminescence.

APPROACH

Approach is based on joint studies of the marine bioluminescence potential (BP) and Inherent Optical Properties (IOPs) over relevant time and space scales, combining recent advances in the bioluminescence research: a novel approach for distinguishing relative abundances of planktonic dinoflagellates and zooplankton (Moline et al., 2009), modeling of nighttime leaving radiance and bioluminescence inversion (Moline et al., 2007 and Oliver et al., 2007) and development of a

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methodology for short-term bioluminescence predictions (Shulman et al., 2003 and 2005). The proposed research is being significantly leveraged by the interdisciplinary and multi-institutional modeling and field efforts of the NRL BIOSPACE and MURI ESPRESSO projects. Bio-optical, physical observations from the following field programs are being used in this study: AOSN I and II (Moline et al., 2007 and 2009, Shulman et al., 2003, 2005, 2009); bioluminescence observations from Monterey Bay surveys conducted by Dr. Haddock (Augusts of 2000, 2002, Decembers of 2002 and 2003 and March of 2004); NRL BIOSPACE-ESPRESSO May-June of 2008 experiment; NRL BIOSPACE planned experiment in October 2010.

WORK COMPLETED

Observations of bio-optical properties (including bioluminescence) together with results from dynamical bio-chemical and bioluminescence models have been used to interpret the development of the upwelling during August 2003 in Monterey Bay, CA.

Dynamical, predictive biochemical, physical and bioluminescence intensity models are combined into a methodology for estimating the nighttime water-leaving radiance due to stimulated bioluminescence at depth. The bioluminescence model described in Shulman et al.(2003 and 2005) was initialized on 14 August of 2003 by using BP data from four AUVs sections: DORADO sections taken 13 August and 14 August, and AUV REMUS sections taken on 14 August (Figure 1). The initialization procedure is described in detail in Shulman et al.(2003 and 2005). After initialization, the bioluminescence dynamics is predicted forward in time by using the advection-diffusion-reaction model. In the NCOM Monterey Bay model (Shulman et al, 2010 and 2007), ecosystem dynamics are simulated by the nine compartment sub-model of Chai et al., 2002 and Fujii et al., 2007. The model simulates dynamics of two phytoplankton groups, two zooplankton grazers, nitrate, silicate, ammonium, and two detritus pools. Phytoplankton photosynthesis is driven by Photosynthetically Active Radiation (PAR), which is estimated based on the shortwave radiation flux from the atmospheric COAMPS model (Doyle et al., 2009). The Penta et al. (2008) scheme is used for PAR attenuation with depth.

We used the constituents from the bio-chemical model to estimate IOPs (absorption and backscattering) based on the methodology outlined in the Fujii et al. (2007). If the intensity of the light from the stimulated BP and IOPs are known, the propagation of the light to the surface can be estimated with the radiative transfer models like HydroLight or a reduced version of Hydrolight-Ecolight model (Mobley and Sundman, 2001a and b). However, in both cases, the use of these models with the coupled, biochemical, physical, nested, data assimilative models are computationally expensive. In the present study we estimated the propagation of light from the BP source to the surface by inverting the Penta et al. (2008) scheme which is used in the biochemical model for attenuating the PAR with the depth. To incorporate the inherent diel rhythms of bioluminescence intensity (with BP intensity greatest at night and lowest during the day), the model predicted BP was multiplied by the time dependent response function of BP. The function was derived from a 4-year half-hourly time series of BP measurements from the Cal Poly pier and AUV REMUS data.

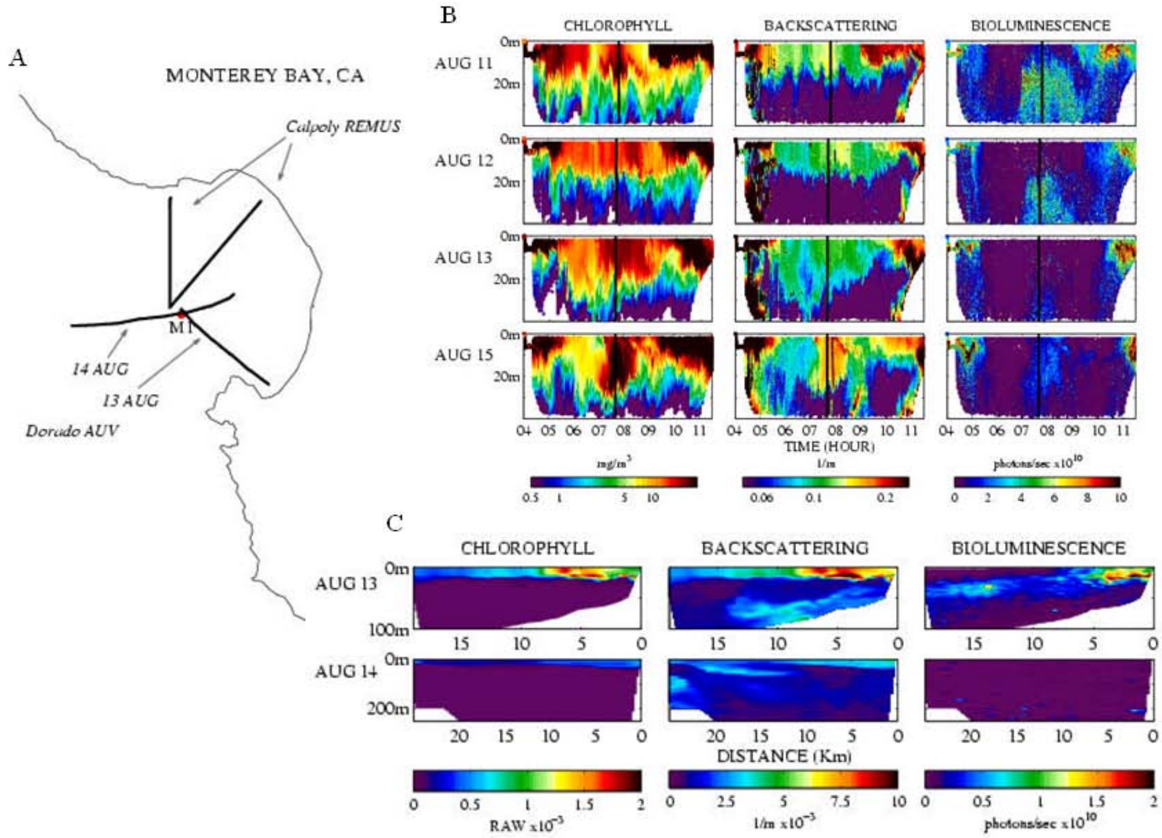

Figure 1. (A) V-shaped transect of CalPoly AUV REMUS and sections sampled by AUV DORADO; (B) AUV REMUS observed chlorophyll, backscattering and bioluminescence during 11-15 August. Solid vertical lines indicate location of the M1 mooring; (C) AUV DORADO observed chlorophyll, backscattering and bioluminescence on 13 and 14 August.

Preliminary estimations of the nighttime water-leaving radiance due to stimulated bioluminescence at depth have been conducted and evaluated. Paper describing results is written and submitted to the refereed journal.

RESULTS

Dynamical, predictive biochemical, and bioluminescence intensity models provide the capability to model and forecast the nighttime water-leaving radiances due to stimulation of BP at depth.

Figure 2 shows water-leaving radiance at the surface (right panels) due to stimulation of the modeled BP intensity over the entire model domain at different depths (5m, 15m, and 25m) on 15 August. The modeled BP 3D distributions (normalized by 10^9) are shown in the middle panels for different depths of stimulations. The left panels show a sum of a (absorption) and b_b (backscattering) integrated from

the depth of BP stimulation to the surface. Values of a and b_b are estimated from the biochemical model in accord with Fujii et al. (2007).

There are high values of estimated water-leaving radiance and BP intensity in the areas close to the coast (Figure 2), which correlates with AUV REMUS observed BP maxima along the coastline (Figure 1). REMUS surveys show coincidence of inshore maxima of chlorophyll, BP and backscatter distributions. This suggests that the inshore BP maximum is associated with the planktonic community (dinoflagellates). This conclusion was supported by using general differences in flash kinetics between planktonic dinoflagellates and zooplankton in Moline et al., 2009. The REMUS observations also show a strong BP signal offshore in the deeper water around the M1 mooring location (center of the entrance to the bay) (Figure 1). This deeper offshore BP maximum is below the observed chlorophyll layer. Low values in optical backscatter in the area of the BP maximum (Figure 1) suggest that this observed deeper BP signal is due to larger zooplankton and probably not due to heterotrophic dinoflagellates. The offshore deep BP signal almost disappeared on August 13 in the center of the entrance to the bay in the REMUS section (Figure 1). The DORADO section also taken on August 13 indicates that the BL maximum is located to the south of the mooring location (Figure 4). This deep offshore BL maximum disappeared on the next day in the DORADO section going through the M1 mooring (Figure 4). On August 15th there is a shallow and weak BP signal coinciding with high chlorophyll and backscatter signals around the M1 mooring, which suggests that planktonic dinoflagellates, not zooplankton, might be the source of this weak shallower BP signal on August 15.

Analysis of observations and bio-chemical model predictions show that the presence of phytoplankton in the center of the entrance to the bay is a result of phytoplankton advection from the northern coast of the bay by the strong southward flow along the entrance to the Bay (Shulman et al., submitted). Because there is a weak BP signal (Figure 1), mostly non-bioluminescent phytoplankton was advected from the north to the mooring M1 location. This suggests that high values of model-predicted BP and water-leaving radiance along the entrance to the bay (Figure 2) are probably an artifact of the modeling. The BP model shows the advection of BP intensity from the northern part of the bay, which is not present in observations as illustrated by the above discussions.

This model-predicted strong BP is illuminated in the surface and subsurface by the relatively lower values of IOPs along the entrance to the bay, which are associated with relatively (to the bay and offshore) clear water masses of the southward flowing jet along the entrance to the Bay (Figure 2). Results presented here indicate the need for improvement of the BP model by incorporating sources and sink terms representing ecological interactions controlling the bioluminescence, as well as behavioral dynamics of bioluminescent organisms (for example vertical migration of dinoflagellates).

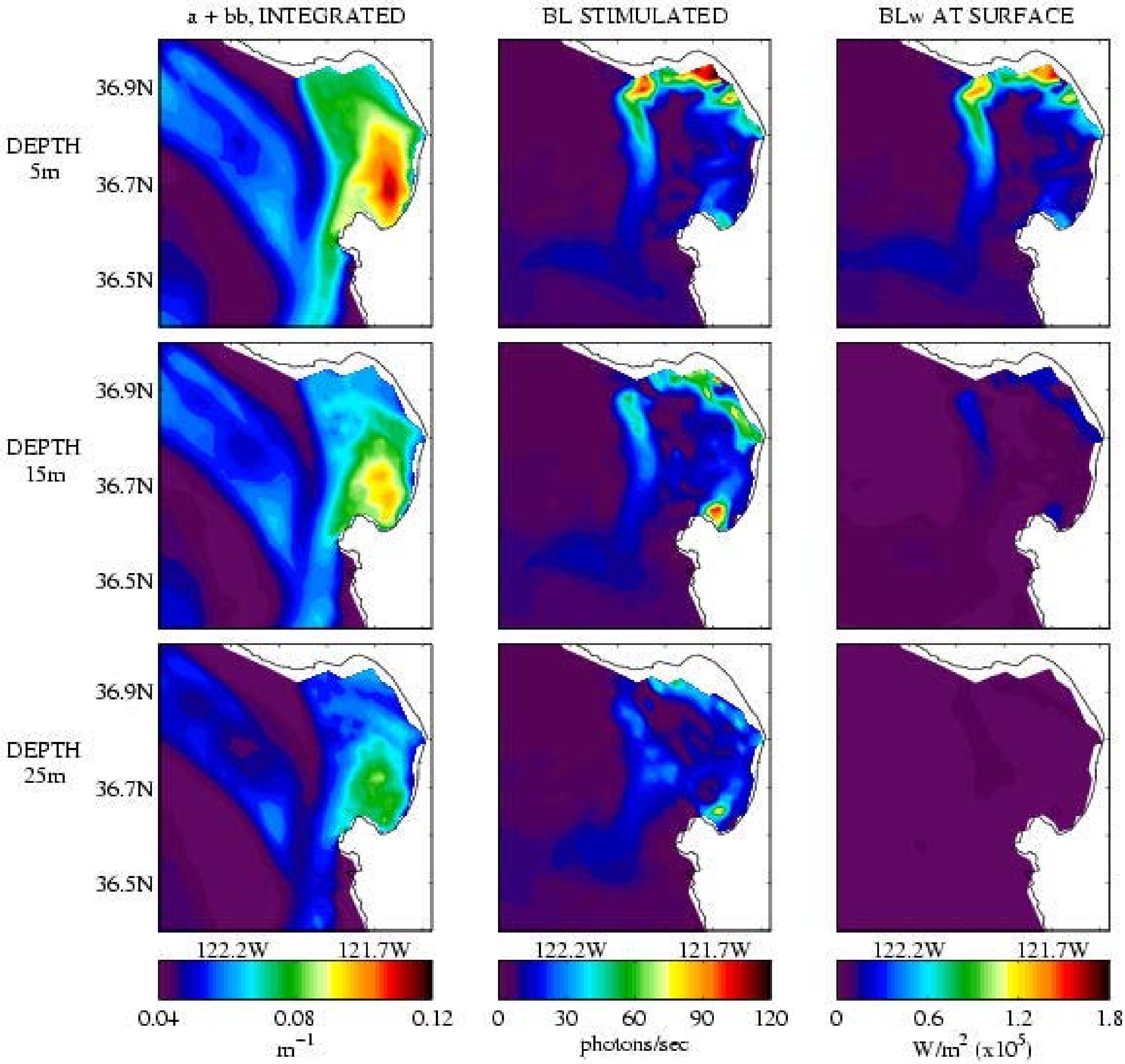

Figure 2. Water-leaving radiance at the surface due to stimulation of the modeled BL intensity at different depths (5m, 15m, and 25m) on 15 August (right panels). The modeled BL intensity for different depths of stimulations (middle panels), and a sum of a (absorption) and b_b (backscattering) averaged from the depth of BL stimulation to the surface (left panels).

IMPACT/APPLICATIONS

Prediction of the location, timing and intensity of bioluminescence potential is critical for numerous naval operations including preventing detection of covert operations involving submarines, Swimmer Delivery Vehicles and AUVs, as well as in aiding detection of enemy incursions. At present, the Navy does not have capability to forecast BP potential and night time water leaving radiance. The proposed

research aims to develop a methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days.

TRANSITIONS

None

RELATED PROJECTS

NRL, RO " Bio-Optical Studies of Predictability and Assimilation for the Coastal Environment (BIOSPACE)" (PI: I. Shulman)

I. Shulman is PI of the NRL project with objectives to improve understanding of the variability and predictability of the underwater light and bio-optical, physical properties on time scales of 1 to 5 days. NRL coupled models and predictions of physical bio-optical properties (including IOPs and BP) are used in our project.

The Multidisciplinary University Research Initiative (MURI) project "Rapid Environmental Assessment Using an Integrated Coastal Ocean Observation-Modeling System (ESPRESSO)" (PIs: O. Schofield, S. Glenn, J.Wilkin, G. Gawarkiewicz, R. He, D. McGillicuddy, K. Fennel, M. Moline).

Objectives of the MURI project are focused on the development of a data assimilative physical-optical modeling-observation system capable of improving predictive skill for forecasting ocean color and improving physical models by using ocean color. M. Moline is Co-PI of the project, and NRL BIOSPACE and MURI project have similar objectives and there are ongoing collaborations between projects.

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PUBLICATIONS

None. A manuscript directly related to this work was submitted to the refereed journal in July, 2010.

HONORS/AWARDS/PRIZES

None.